Meeting digital challenges in the sector

The wine industry—like all business sectors—has undergone a digital revolution. This transformation has provided a unique opportunity for stakeholders in this sector to benefit from very high definition information and thus enhance monitoring and management of their production systems.

New technologies have led to a marked increase in data that can be acquired through wireless sensor networks or weather stations, machine-mounted or hand-held data logging systems, and remote-sensing platforms (unmanned aerial vehicules, airborne devices, satellites). Data concerning vines and the vineyard environment (climate, soil, etc.), as well as wine processing, making and marketing processes, are acquired at an unprecedented spatiotemporal resolution. This generates very high flows of diverse data which have to be processed, analysed, shared, disseminated and stored prior to their use and development. An incredible wealth of high volume data is now available, which could serve to design very effective decision support tools for the wine industry , provided professionals have access to tailored methods to develop their products in response to market trends and climate change. These methods must meet a dual challenge.

First, all upstream (agricultural and environmental) and downstream (transformation processes, consumption patterns, etc.) data must be linked via advanced data integration techniques, knowledge (disciplinary or business related) and models. Secondly, knowledge must be extracted from data by modelling and/or by inference on phenomena whose complexity has until now been hard to grasp. The tools and methods developed will facilitate assessment and management of new systems while ensuring the sustainability of the sector through an integrative approach. They will meet needs with regard to representation, diagnosis, assessment and decision support for various issues, including crop protection, environmental assessment, input management, product quality management, etc. New complex system design methods will also be proposed for innovations in, for instance, equipment sizing and types, while developing new cropping systems, breeding new varieties adapted to new constraints, and capturing new market shares.

The Agropolis scientific community has the expertise and facilities necessary to come up with effective responses to the major challenges of the digital revolution. They raise research issues for the entire viticulture and wine sector at organizational, spatial and temporal scales. Several research units are aware of the importance of digital challenges in the fields of agronomy and environment. They hence focus their methodological research—in collaboration with their national and international, public and private partners—on addressing the challenges that arise. The fact that specialized engineering science, mathematics and informatics research units, as well as thematic research units in viticulture, ecophysiology, oenology, etc., are pooled within Agropolis promotes interdisciplinarity and is a prime asset.

A first type of research concerns issues associated with measurements obtained via automated or manual recording devices. They encompass the design of: i) new sensors, ii) methods to ensure data quality, and iii) innovative systems for organizing and sharing information.

A second type of research deals with specific issues related to the influx of geolocalized data in the precision viticulture framework, e.g. the design of spatial data sampling and processing methods that take wine trade knowledge into account.

Finally, the last type brings together research in different areas: i) the analysis of huge volumes of heterogeneous data (spatiotemporal) collected in vineyards or wine cellars, ii) data- and knowledge-based modelling, and iii) simulation-based modelling.

A major share of the research conducted by the community in all of the fields presented in this chapter concerns the effective use of data via simulation and decision-support software packages, which are essential for identifying new uses and implementing innovative practices.

Brigitte Charnomordic (UMR MISTEA)
& Bruno Tisseyre (UMR ITAP)

Meeting digital challenges in the sector

Development of information acquisition and usage tools and methods for decision support

Research carried out by the joint research unit **Information-Technologies-environmental Analysis-agricultural Processes (UMR ITAP – IRSTEA, Montpellier SupAgro)** fulfils needs regarding information acquisition and its use in life science, agriculture and environmental applications. The research findings have many applications in viticulture—a field in which the team has developed substantial expertise on instrumentation and field experimentation.

Main teams
UMR ITAP **Information-Technologies-environmental Analysis-agricultural Processes** (IRSTEA/Montpellier SupAgro) *25 scientists, with 14 involved in the topic*
UMR LIRMM **Montpellier Laboratory of Informatics, Robotics and Microelectronics** (UM/CNRS) *170 scientists, with about 10 involved in the topic*
UMR MISTEA **Mathematics, Informatics and Statistics for Environment and Agronomy** (INRA/Montpellier SupAgro) *18 scientists, with 11 involved in the topic*
UMT ECOTECH-VITI (IFV/IRSTEA/Montpellier SupAgro-IHEV) *6 scientists*
Other teams focused on this topic
Domaine du Chapitre Experimental Unit (Montpellier SupAgro/INRA) *7 engineers and technicians*
UMR SPO **Sciences for Enology** (INRA/Montpellier SupAgro/UM) *45 scientists*
Pech Rouge Experimental Unit (INRA) *6 scientists, 30 engineers and technicians*
UMR LEPSE **Ecophysiology of Plants Under Environmental Stress** (INRA/Montpellier SupAgro) *15 scientists, with 5 involved in the topic*

UMR ITAP develops tools and methods applied to all stages from information acquisition to usage for decision support, including:

- development of new nondestructive sensors based on spectral properties of the environment (soil, fruit, leaves, etc.): the Optical Sensors for Complex Environments team develops scientific and technical benchmarks for characterizing agroecosystems by fine tuning optical sensors in hyperspectral imagery and near-infrared spectroscopy, and associated processing methods. The team has a state-of-the-art instrumental optics laboratory.
- design of decision systems tailored for sustainable agroenvironmental processes: the Modelling for Agroenvironmental Decision-making team develops scientific and technical benchmarks for designing decision-support system tools to diagnose system conditions and precision agriculture approaches. The methods involve fuzzy logic, discrete event systems and geostatistics.
- development of methods and tools to reduce pesticide use and impacts on the environment and on the health of operators and inhabitants in the vicinity of treated plots. The Processes-Environment-Pesticides-Health team studies spraying processes, from the spray nozzle to pesticide transport, on catchment and territory scales. The team relies on the ReducPol technological research platform, which has unique experimental expertise and facilities in France devoted to studies on spraying phenomena and pesticide transfers in the environment.

The research unit has regular scientific exchanges with several international partners, including the Australian Centre for Precision Agriculture, the Universities of Sydney (Australia), Talca (Chile), Lleida, Pamplona, Madrid and Córdoba (Spain), etc.

The unit mainly conducts targeted research in close collaboration with various economic stakeholders, including private companies—startups, very small enterprises (VSEs), SMEs, medium-sized enterprises (MEs), large groups technical institutes on collaborative projects (ARVALIS, CTIFL*, IFV, ITB) or regional experimental stations (CEHM)**.

In public policy support missions, the unit conducts studies for national agencies (ONEMA, ADEME, ANSES***), the French Agriculture and Environment Ministries and local authorities.

* CTIFL: *Centre technique interprofessionnel des fruits et légumes* (France)
**CEHM: *Centre expérimental horticole de Marsillargues* (France)
***ONEMA: French National Agency for Water and Aquatic Environments
ADEME: French Environment and Energy Management Agency
ANSES: French Agency for Food, Environmental and Occupational Health and Safety

▲ *A drone photographing a vineyard*
© G. Besqueut

AgroTIC Services – ICT specialists offering technical expertise for wine companies

The digital world is constantly and rapidly changing. AgroTIC Services is a technical unit devoted to meeting the growing support and training needs of the wine sector regarding ICT issues. This specialized unit—coordinated by Montpellier SupAgro and UMR ITAP—was designed to serve as a clearly identified business partner to address all issues regarding the use of these new technologies in agriculture, especially in the wine sector.

Educational, support and monitoring activities carried out by AgroTIC Services enable companies to set up projects linked directly with teaching or research.

These activities are organized around four main foci:
- educational activities to strengthen links between education and business
- continuing education for agricultural professionals
- seminars for research stakeholders, students, agricultural businesses and ICTs
- individual business support on R&D projects in the agricultural ICT field.

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▲ *Spectron™, a portable sensor for monitoring grape ripening* © Pellenc SA

Development of new portable sensors such as the Spectron™

VINNOTEC (2007-2012) was a major collaborative R&D project coordinated by UMR ITAP, pooling driving forces of public and private research.

The project aimed to integrate ICTs in all steps of the vine-cropping and wine-production process. ICTs ensure precise spatiotemporal information, real-time market reactivity and the creation of new viticulture and wine knowledge bases. These technologies facilitate the emergence of new products and services tailored for different links in the production chain. New sensors are used to effectively characterize the state of the vines, grapes and fermentations. This helps streamline the associated production process via decision-support services.

This project gave rise to a number of tools and services that are now (or about to be) marketed, including sensors for vine and fermentation monitoring. The Spectron™—one innovation proposed by the VINNOTEC project—is a portable sensor for monitoring grape ripening. This tool is used to autonomously monitor grape ripening parameters (sugar content, acidity, anthocyanins, etc.) directly in vineyard plots. The sensor is based on visible and near-infrared spectroscopy technology. It is the result of nearly 10 years of collaborative research between UMR ITAP and the French company Pellenc SA.

The VINNOTEC project—certified by the *Qualiméditerranée* competitive cluster—was supported by the French government (Single Interministerial Fund [FUI]), Languedoc-Roussillon Region, OSEO and the European Regional Development Fund (ERDF).

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Spatialization of viticulture data

Medium to high resolution spatial data are now widespread in the viticulture sector (GPS, onboard sensors, remote sensing, etc.). This phenomenon has generated a demand for advanced spatial information display, handling and processing tools. Due to the technical, social and economic features of the sector, it is essential to develop specific methods in order to provide the wine industry with easy to use, sturdy and inexpensive (or even free) tools that are tailored to specific trade needs. The following examples illustrate recent advances in this field.

Optimizing spatial sampling

Spatial sampling—in an experimental or operational setting—is necessary to characterize the status of a vineyard plot at a given date. It is essential to carefully plan the sample number and positions in order to achieve quality estimates. High spatial resolution data (remote-sensing) helps determine the spatial variability of the studied area and thus to optimize the position and number of measurements to carry out. Research conducted by UMR ITAP aims to produce generic spatial sampling methods that are optimized and specifically tailored to viticulture parameters such as yield estimation using vegetation maps obtained by remote sensing imagery (UAV, airborne devices, satellite).

▲ *A drone photo of a vineyard*

© G. Besqueut/UMR ITAP

Optimizing selective grape harvesting routes

Research studies are focused on complex optimization problems with specific applications to vineyards and wine cellars (LIRMM, ITAP and MISTEA collaboration). By integrating spatial data, these constraint programming methods address major logistical and organizational issues, like those regarding selective grape harvesting. This involves separately harvesting two qualities of grapes on the same plot with a two-hopper mechanical grape harvester. The location of quality grape zones and the estimated quantities to harvest are known. The problem is to optimize the route of the harvester in the vine plot, while addressing many constraints—consideration of the row harvesting direction, harvester storage capacity, etc.

Mapping the water status in vineyards

Monitoring the vine water status on a plot, vineyard or territorial scale is essential to help wine growers make decisions with regard to managing the quantity and quality of the end product. Since 2010, UMR ITAP, with UE Pech Rouge and IFV, has been developing empirical models to extrapolate, spatialize and map the vineyard water status. The original aspect of the approach is that it makes effective use of point data acquired during operational monitoring of the vine water status. An innovative participative production approach (crowdsourcing) could be used with this method. Growers could thus share, consolidate and enhance a spatiotemporal database focused on monitoring the vine water status on a territorial scale. This would enable dynamic learning of a spatial model that is perfected gradually as the database is enhanced.

▲ *Extrapolation of a benchmark water status measurement (reference measurement site) at a given date and at the cooperative area scale*

Interpolated map plotted on the basis of historical reference data—estimation quality at measuring stations not used for model learning (0.10 Mpa).

© UMR ITAP

GeoFIS project

Agropolis teams specialized on the development of operational methods have designed the free open source software platform GeoFIS to facilitate transfer of their research results. This simple scalable toolbox offers the possibility of adding new spatial data processing functions. GeoFIS is designed for quick transfer—through a simple interface—of innovative methods that can be implemented by professionals or students for specific applications. The functions developed in the framework of the GeoFIS project could be incorporated as plugins in GIS software.

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For further information on GeoFIS: https://prezi.com/8f4gifhshycl/geofis

Constraint programming and learning

The joint research unit **Montpellier Laboratory of Informatics, Robotics and Microelectronics (UMR LIRMM – UM, CNRS)** includes three departments: Informatics, Robotics and Microelectronics.

The Informatics department involves 14 project teams spanning a broad spectrum of informatics research, ranging from theoretical informatics to applications and interfaces with many other disciplines. The applications concern genomics, molecular and cellular biology, medicine, agronomy, biodiversity preservation, oenology and precision viticulture, etc.

Within the Informatics department, the COCONUT (Constraints, Learning, Agents) team is part of the Artificial Intelligence research platform, which proposes and studies artificial intelligence models and algorithms. This team focuses on problems arising through the use of technologies derived from constraint programming and learning, with a marked theoretical foundation and algorithm component. It deals with constrained optimization problems, especially numerical optimization, and standard learning or data mining issues with a constraint-based approach.

In the viticulture and wine field, several prototypes have been developed in collaboration with UMR ITAP and UMR MISTEA, and with the companies Nyseos and Fruition. These initiatives deal with various issues: optimization in selective harvesting of the route of a two-hopper grape harvester; optimization of the schedule and route of technicians for monitoring water stress in 200 vineyards; and optimization of the blending of several wines while taking volume and aroma profiles into account.

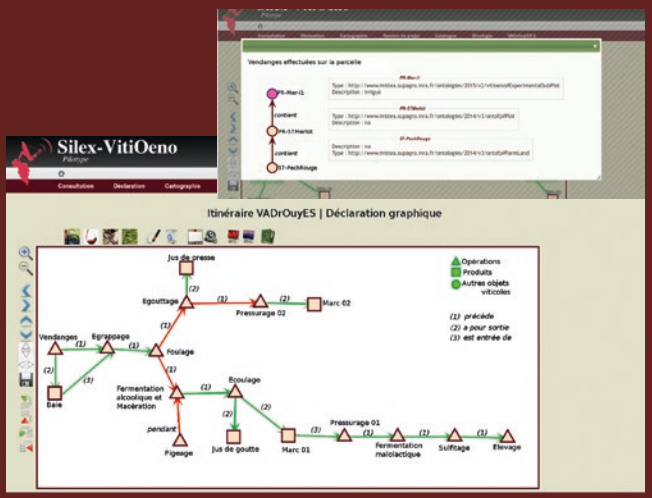
SILEX project
A promising information system for viticulture and wine experimentation

Since 2010, the collaborative Information System for Experimentation (SILEX) project, coordinated by UMR MISTEA, has been proposing information systems tailored to meet new data-related challenges for scientists and researchers. SILEX has led to the creation of several production information systems focused on viticulture and winemaking (UMR SPO, UMR SYSTEM, Pech Rouge UE).

SILEX can manage and temporally monitor entities such as plots, microplots, vines, organs, etc. Knowledge engineering and innovative semantic web technologies are used for this task. Domain-specific ontologies enable vocabulary control, event or transaction annotation, reasoning and data sharing, etc.

An annotation app for tablets and mobile phones is provided to improve the traceability. From a greenhouse, cellar or field, an operator can thus annotate entities identified by QR codes and declare a fallen pot or disease signs observed in a grapevine row. This can be associated with videos, audio recordings, photos or handwritten notes, and fermentation curves are enhanced by these annotations. Implicit or lacking events are also taken into account through business rules and reasoning. The knowledge produced can be exploited via statistical analysis treatments, and especially automatic data validation.

SILEX enables users to specify operations and products (grapes, must, etc.) in a production process. It visualizes this process while including associated data and analytical results, applied treatments, events, etc.



▲ *Screenshots of Vadrouyes. A web application for the declaration and consultation of vinification (a) and viticultural (b) practices* © UMR MISTEA

SILEX is widely used for bioprocesses (UR Laboratory of Environmental Biotechnology) and high throughput phenotyping of plants (UMR LEPSE). In this field, SILEX will equip nine platforms of the French national PHENOME project (see *p. 55*), ranging from the plot to the gene scale.

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Experimental agricultural data – from organization to prediction and decision support

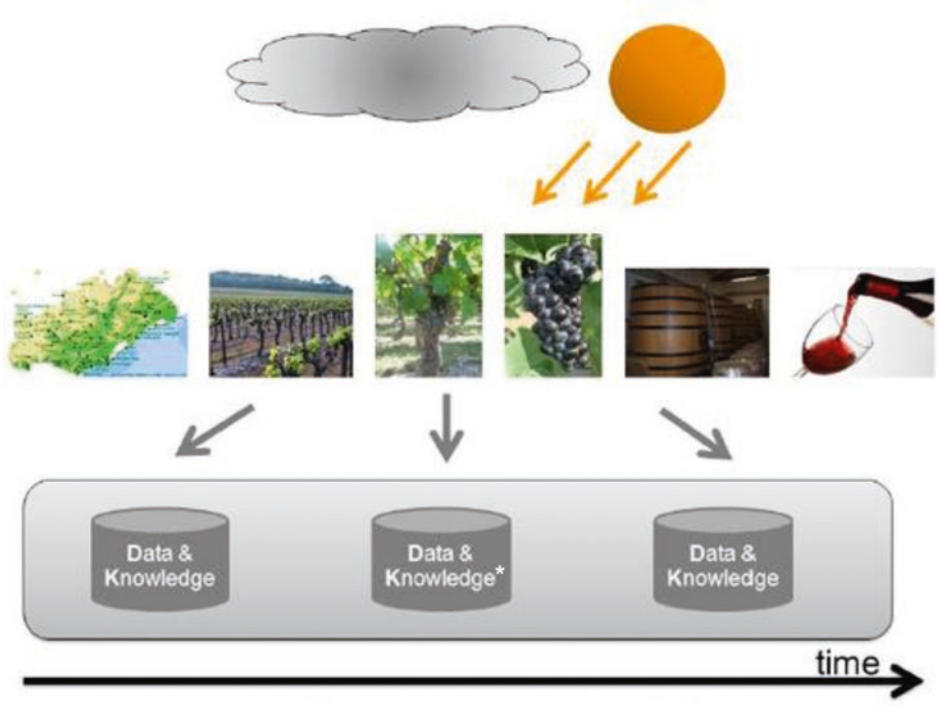
The joint research unit **Mathematics, Informatics and Statistics for Environment and Agronomy (UMR MISTEA - INRA, Montpellier SupAgro)** develops methodological mathematics and informatics tools for agricultural and environmental science applications. This unit pools researchers from the INRA Applied Mathematics and Informatics Division and the Montpellier SupAgro Department of Sciences for Agro-Bio-Processes.

MISTEA proposes innovative solutions to meet current challenges regarding the integration of experimental agronomic datasets that are increasingly large, heterogeneous and acquired at different scales. Synergies generated by the presence of computer scientists and statisticians with a broad range of expertise in data management, analysis and modelling enable the unit to implement an integrated approach ranging from data organization to prediction and decision support. The viticulture and wine sector is a prime focus of the unit's research.

The unit proposes an original semantic graph based approach to collect and organize multiscale data from mixed sources. Ontologies* enable the formalization of knowledge to facilitate sharing between different groups and the use of this information in automated reasoning. A large-scale study carried out recently with the Pech Rouge research unit resulted in the development and correlation of ontologies regarding viticulture and winemaking. Automatic data validation and preprocessing methods make it possible to combine expert information and statistical methods. An emerging prediction and decision-support challenge concerns the comparison of plant or fruit evolutionary data to a high number of cofactors, such as genetic or environmental information. MISTEA is developing advanced methods that combine curve analysis (functional statistics), high-dimensional statistics (variable selection), multiscale integration (hierarchical models) and classification (clustering).

The research unit is involved with public and private partners in different projects in the sector: the 'Long-term adaptation to climate change in viticulture and enology' programme (LACCAVE, *see p. 58*), the 'Development of a decision-support tool to enhance the competitiveness of wines for export' project (PILOTYPE, 2010-2014) coordinated by a consortium of major stakeholders in the sector, and the 'Data integration and expertise for a new generation of viticulture tools' project (IDENOV, *see next page*), winner of the Global Innovation Competition in July 2014.

*A computer model representative of a set of concepts within a domain and logical relations between them.



▲ *A chain-based approach*
© MISTEA

▲ *Flow capture device* © S. Payen/Fruition Sciences

IDENOV project
Data integration and expertise for a new generation of viticulture tools

The IDENOV project is coordinated by Fruition Sciences—a service company that provides wine growers with an integrative, terroir and vintage-specific, data-driven web application. The project is geared towards the integration of 'data science' innovations in the wine sector. It makes effective use of a highly diverse range of data from sensors placed in vineyards (sap flow and temperature sensors, etc.), associated with field expertise. Three partners are collaborating to achieve the objectives: Fruition Sciences, UMR MISTEA and Global Vision (a service support company implementing the open innovation strategy).

The project—through the development of a method tailored for the analysis of complex data—led to the development of a first prediction tool based on data collected in vineyards over several years.

The method combines multidimensional exploratory analysis techniques extended to temporal data and high-dimensional statistical methods that enable the construction of interpretable parsimonious models by estimating a limited number of parameters. This approach facilitates the discovery of periods and factors that have the greatest impact on grape quality (measured by physicochemical analysis) while building the founding elements of an automated decision support tool.

In the era of the digital revolution, and the massive influx of heterogeneous multisource data, this project is emblematic of the methodological advances achieved. The latter are geared towards tapping all of these data to build a new generation of tools for the viticulture and wine sector. The project was the winner of phase 1 of the Global Innovation Competition in 2014*, in the Big Data challenge.

** www.entreprises.gouv.fr/innovation-2030/accueil-innovation-2030*

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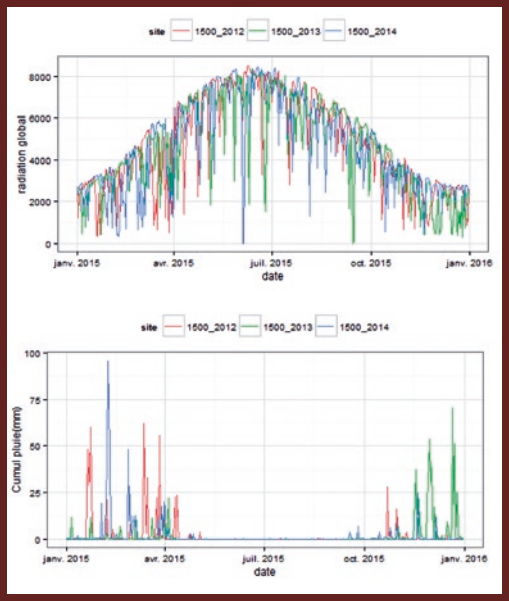
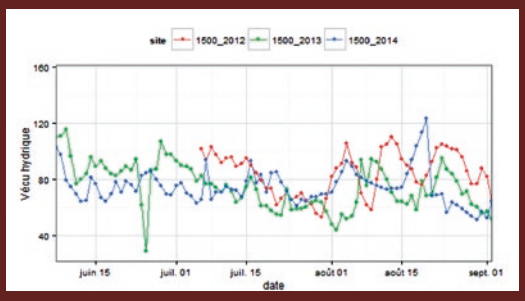
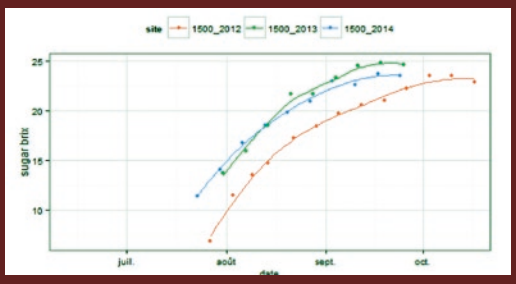
Climate data



Plant data



Fruit data



▲ *Correlating heterogeneous data at different temporal scales: weather data (sunlight, rainfall, etc.), vine water status, grape quality*
© S. Payen/*Fruition Sciences*

▲ *Irrigated vines* © S. Payen/*Fruition Sciences*

SOFA – oenological alcoholic fermentation simulation software

The SOFA software package—available in English, French, Italian and Spanish—is the result of a several year collaboration between the MISTEA and SPO joint research units. This collaboration resulted in the development of a physiological model of alcoholic fermentation. The model was validated with real data on several dozens of fermentations conducted in different conditions (sugar and nitrogen contents, temperature). The software is marketed by the company INTELLI'OENO.

SOFA can predict the course of alcoholic fermentations (fermentation rate, time, sugar consumption, released energy, etc.) on the basis of a few initial key data, such as grape must analytical parameters (sugar and assimilable nitrogen contents) and fermentation conditions (temperature profile, nitrogen nutrient supplementation, fermentation onset date, tank volume).

SOFA is a two-part software package:

- SOFA 1 enables detailed prediction and viewing of the effects of key parameters (e.g. temperature, nitrogen content or nitrogen nutrient supplementation) on the course of alcoholic fermentation.
- SOFA 2 enables optimization of instantaneous and total frigorie requirements during the vinification process, as well as the tank occupancy (by adjusting the fermentation time).

SOFA is a pioneering example of modelling complex systems through a combination of data and knowledge related to the main physiological mechanisms of yeast and formalized by differential equations. The knowledge model is supplemented with many experimental data and the variables are dissociated so as to be able to identify the model parameters. SOFA illustrates the success of an interdisciplinary approach in which mathematicians, microbiologists and computer scientists interacted in the research and came up with an operational solution. MOMAF (for 'modelling of the main reaction of alcoholic fermentation') is a very recent SOFA software extension that can simulate the kinetics of higher alcohols and esters.

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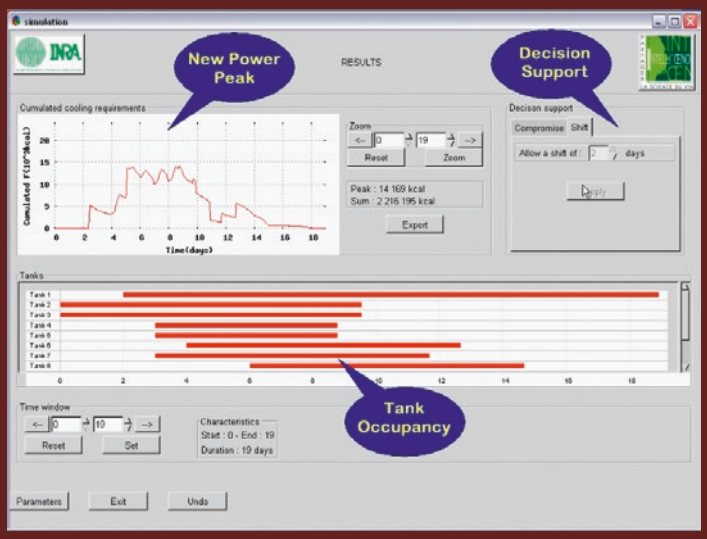

▲ *SOFA software interface* © B. Charnomordic

© F. Pruneau

▲ ▶ *Tablet annotation of observations and events during vine experiments on the vine phenotyping platform in the field*

PHENOME – the French plant phenotyping network

PHENOME (2012-2019) is a French National Biology and Health Infrastructure of the Investments for the Future programme. It aims to provide the French plant research community with a network of high-throughput phenotyping platforms (*see p. 12*), to facilitate characterization of the responses of genotype collections of different species to various environmental scenarios (associated with climate change)—many experiments have already been undertaken on grapevine. The infrastructure consists of: (1) two platforms under controlled conditions, (2) two field platforms under semi-controlled environmental conditions, and (3) three field platforms under non-controlled conditions.

All of the platforms are equipped with a complete set of functional 3D imaging techniques, for: detailed imaging of roots and shoots under controlled conditions, canopy imaging with an autonomous *phénomobile*, which captures functional 3D images of individual plots, and drones which capture images of hundreds of plots together. Two omic platforms also centralize metabolomic and structural measurements associated with experiments.

Two methodological projects coordinated by UMR MISTEA develop infrastructure for methods and techniques capable of: (1) organizing data from different platforms so that they can be stored and analysed over a long period by a broad ranging scientific community, and (2) designing and disseminating—to the academic community and industry—a new set of methods for data analysis and the extraction of genotypic traits (data annotation and validation, modelling, links with plant and crop models).

PHENOME has already led to the creation of phenotyping and precision agriculture SMEs (including one spin-off and several patents). It is incorporated in European and international phenotyping projects (European Plant Phenotyping Network, International Plant Phenotyping Network, European roadmap).

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